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An integrated approach for landscape contrast analysis with particular consideration of small habitats and ecotones

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Abstract

Habitat diversity is considered as an expression of biodiversity at landscape level in addition to genetic and species diversity. Thus, effective methods for measuring habitat pattern at landscape level are crucial for understanding the ecological processes. In this paper we propose to extend the commonly used model Patch Corridor Matrix Model (PCMM) for spatial pattern analysis. Originally, this model assumes discrete structures within the landscape without explicit consideration of "gradients" between patches. The gradients, often called "ecotones", can be considered as "soft edges" which have a profound influence on adjacent ecosystems. Another part of information that has often been ignored are "small habitats" inside patches (e.g. hedgerows, tree rows, copse, and scattered trees), which leads to within-patch heterogeneity being underestimated. In this paper, the concept of landscape contrast is used to integrate the discrete and gradient landscape representations by incorporating small habitats and ecotones in methods to measure landscape heterogeneity. A height gradient is used to define the ecotones between forest and field. Then, patch contrast (i.e. Edge Contrast Index (ECON)) is calculated based on the height difference between adjacent vegetation patches. Artificial elements (e.g. traffic roads) are considered as barriers which are assigned with the highest edge contrast value. At the landscape level, a metric called Area-Weighted Edge Contrast (AWEC) is introduced to describe the landscape structure. The edge effects of ecotones, small habitats, and traffic roads are incorporated in the calculation of AWEC. Our test examples show that incorporation of ecotones and small habitats can smooth "edge effects" among patches and result in a more realistic quantification of habitat contrast. The contrast concept is especially useful in a vegetated landscape with less human impact. It could be understood as an additional interpretation to fragmentation of habitats with permeable edges among them. Consequently, this presented approach may enhance the understanding of the relationship between landscape pattern and process.

Keywords
Patch corridor matrix model, gradient model, ecotones, small habitats, habitat fragmentation

Introduction

Landscape metrics based on the mosaic model are often used in landscape analysis. In practice the application of this model may be over simplified by losing valuable information on the landscape structure, such as the terrain characteristics of landscape (Hoechstetter 2008, Walz et al. 2007), transitional areas between patches (Kent et al. 1997), and small habitats within patches (Hou and Walz 2013). Kent et al. (1997) defined transitional area as a subset of landscape boundaries that represents the zones between plant communities with some degree of naturalness, as opposed to the sharper demarcations that usually occur between land-use types. Ecotone as a type of transitional area indicates the overlap or zone of relatively rapid change between two plant communities (Forman 1995, Kent et al. 1997). It has a profound influence on adjacent ecosystems, for example, ecotones control the flux of materials and energy between ecosystems (Fortin et al. 2000), functioning as ecological boundaries that contribute to the spatial heterogeneity of the landscape (Cadenasso et al. 1997, Fagan et al. 2003, Holland et al. 1991, Senft 2009, Strayer et al. 2003). Small and linear vegetation patches (e.g. scattered trees, hedgerows, tree rows and groves) are of high natural value for the conservation of biodiversity (Ernoult and Alard 2011, Forman 1995, Morelli 2013). The main functions of these small habitats in ecosystem are either providing habitats for some edge species or forming a network to strength the species movement, such as hedgerow network (Burel and Baudry 1995, Forman and Baudry 1984).

With the development of remote sensing technology, it is possible to direct map the small habitats or discriminate different types of habitats occurring in spatially contiguous units (Bunting and Lucas 2006, Corbane et al. 2015, Hill et al. 2007, Hirschmugl et al. 2007). Especially the combination of LiDAR (Light Detection And Ranging) data and high resolution images has been proved to be useful in mapping tree crowns and measuring individual tree structure (Holmgren et al. 2008, Hou and Walz 2014, Morsdorf et al. 2004, Smart et al. 2012). However, the advantages of remote sensing technology in habitat mapping are not fully utilized. Among the large amount of existing landscape metrics, there is still lack of metrics which can fully incorporate ecotones and small habitats in the landscape structure analysis. The metrics used for analyzing landscape structure are dependent on the conceptual model for representing the landscape. McGarigal et al. (2009) introduced surface metrics as an alternative to patch metrics for the quantification of landscape gradient structure. Hoechstetter et al. (2011) used lacunarity analysis to analyze gradual value progressions in landscape systems. The both methods consider the landscape as a continuous surface instead of the patch mosaic model. The surface metrics are derived from a raster based data in which the only discrete unit is a pixel or grid cell (Lausch et al. 2015). In this paper,

the landscape is regarded as a mosaic with discrete patches and permeable boundaries between them (intermediate edge contrast). The focus is on developing or adapting suitable metrics to incorporate the ecotones and small habitats as crucial factors in the analysis of landscape structure.

Landscape heterogeneity has been integrated into metapopulation theory by incorporating habitat fragmentation and landscape contrast (Biswas and Wagner 2012). The fragmentation indices consider both composition and spatial pattern of landscape, but the boundaries between patches are either regarded as not permeable (highest contrast) or as full permeable (no contrast). In other words the patch borders are abrupt in the use of fragmentation concept. In contrast, landscape contrast has been considered as a crucial factor for assessing habitat pattern across different scales (Biswas and Wagner 2012, Schindler et al. 2008). Edge contrast affected the magnitude of edge effects, with a tendency for stronger responses to old and tall plantations (hard edges) than to young and short plantations (soft edges) (Reino et al. 2009). For example, in the form of passive dispersal, seeds will accumulate on the forest boundary as plants dispersed by wind; or the "terrain barriers" can act as obstacles for the movement of certain species. Ecotones can reduce the edge contrast value on both edges of plant communities. In particular, the degree of patch contrast may influence species dispersal patterns, and thus indirectly affect the degree of patch isolation. The objective of this research is to integrate both ecotones and small habitats in landscape contrast analysis which results in a detailed and comprehensive description of landscape pattern.

Methods

Applied concepts and test sites

In this paper, the ecotone is defined at a detailed spatial level as a "soft" boundary between forest and field. It has a three dimensional structure appearing as gradual blending of the two plant communities on the boundary area, where the third spatial dimension (vegetation height) is used to constrain the transition zone on forest-field boundary. It refers to mixed vegetation above the field layer but below the overstory formed by a combination of side branches of canopy trees, small trees, lianas, and shrubs. The small habitats (including single trees, tree rows, hedges, and copses) are defined by an area less than 0.5-1 hectare, a minimum width of 5 m and the occurrence in the field, isolated from forest (BfN 2002). The small habitats can be distinguished from their shape features. For example, hedges are defined as shrub-dominated structures, while a copse is characterized by several or dominating trees in the vegetation stand. A tree row is a line of trees exhibiting a long and narrow outline.

Two test sites with varied landscape structure are selected from the German national park "Saxon Switzerland", which is located in south-eastern Germany (Figure 1). It is a mountainous area largely covered by forest, encompassing several types of land use structures and classes, mainly including rural settlements and surrounding agricultural

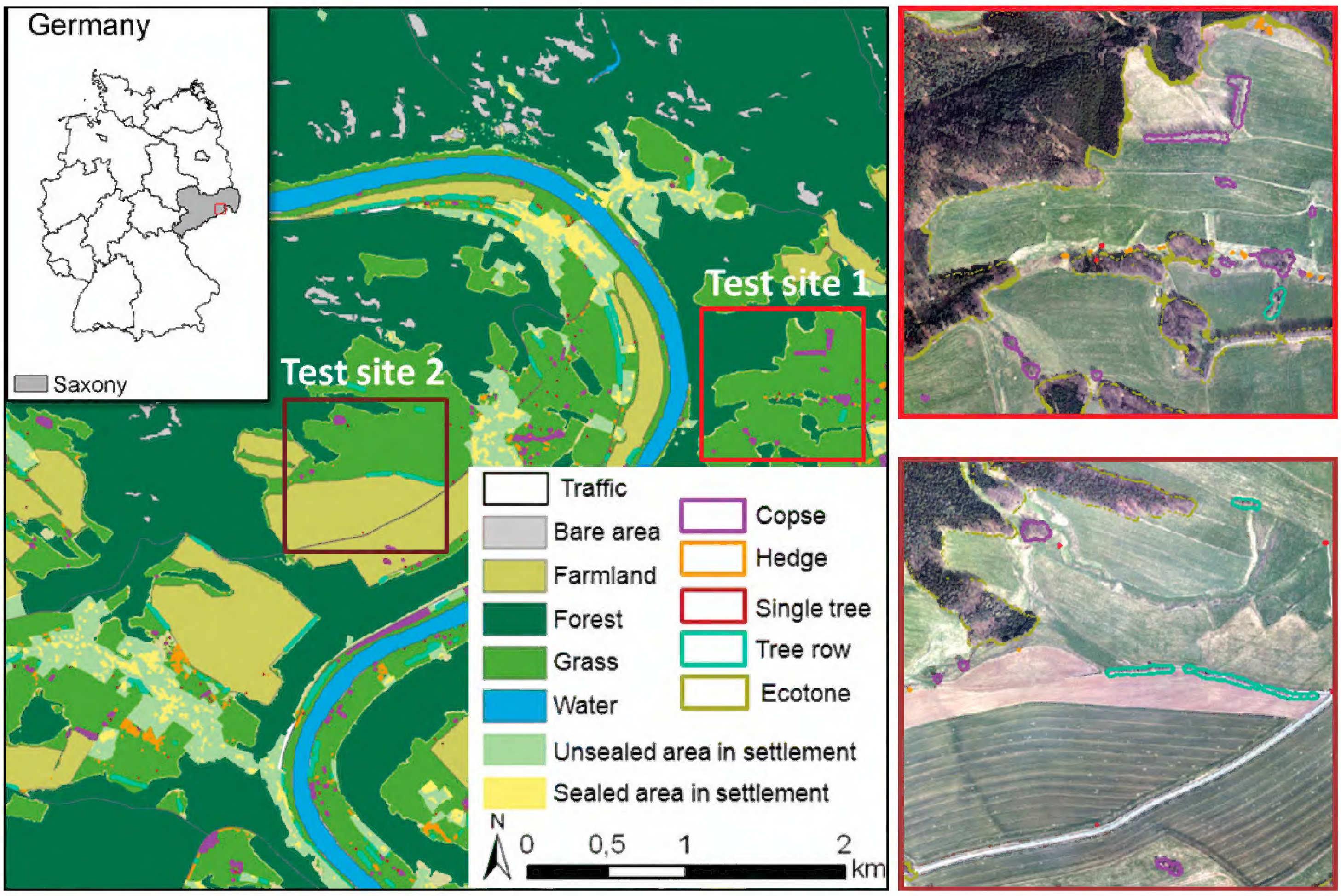

Figure 1. Classified land use maps including small habitats and ecotones in two test sites located in Saxon Switzerland.

land. A very detailed land cover map of this region including ecotones and small habitats was produced from the combination of RapidEye remote sensing images and a high resolution normalized Digital Surface Model (nDSM, 1 m resolution) which was derived from LiDAR data (see detail in Hou and Walz 2014).

Patch contrast

Patch contrast is used to describe the relative difference between patches or patch classes; for example "edges" have a kind of "contrast effect". A strong contrast value means that adjacent patches differ strongly and the transitions between them are narrow or even absent (Forman 1995). Of relevance to the contrast of vegetation cover, the "dissimilarity" or "edge contrast weight" can be derived from the difference in height among habitats. The contrast value is highly related to the conceptual model used for simulating the landscape. Categorical landscape models ignore within-patch heterogeneity and emphasize contrast between adjacent patches. Specifically in this research, ecotones between forest and field are defined as height gradient and the boundary behavior is related to the transition forms, such as a thin border or a broad transition zone with mixed vegetation. In this case, the vertical structure is used as a means that integrates discrete and gradient forms of spatial heterogeneity. Such differences have rather easily deducible ecological consequences. The forest along an ecotone is less iso-

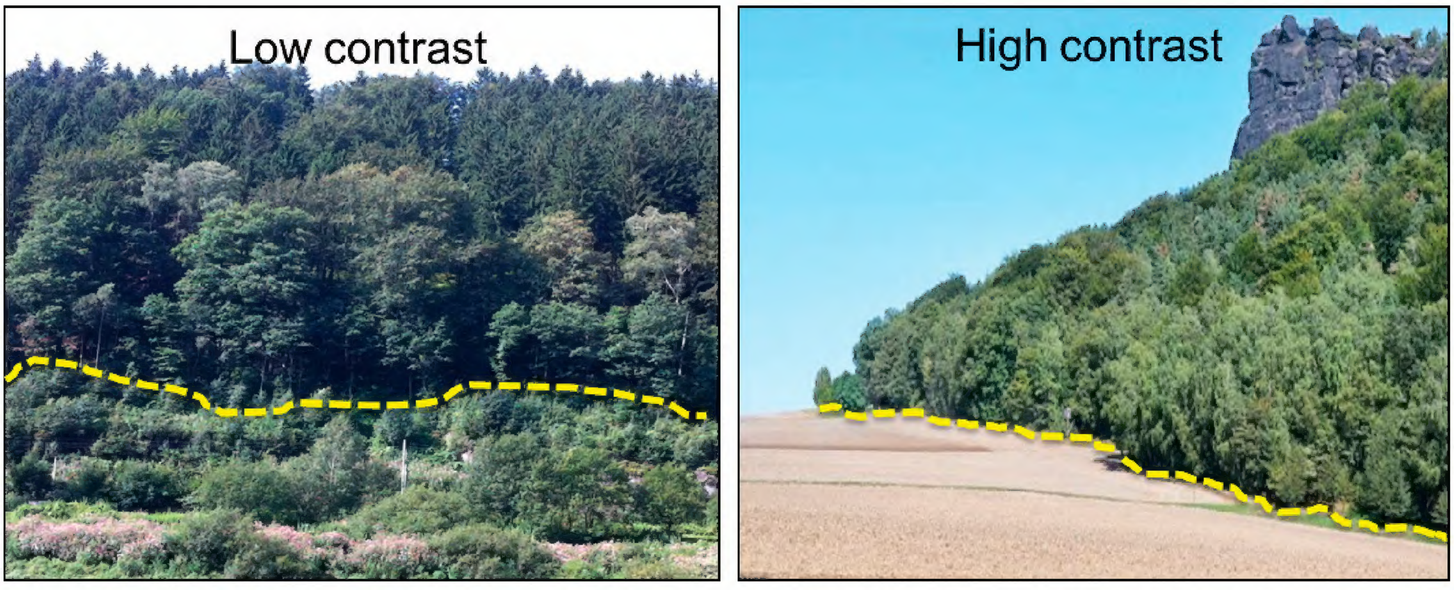

Figure 2. Examples of contrast magnitude along patch edges in "Saxon Switzerland", Germany (Photos: Hou).

lated than along the bare soil (agriculture land) (Figure 2.2). Artificial elements, such as traffic roads, are considered as barriers which present high contrast and can be assigned with the highest edge contrast value.

In this context, a height-based variant of the Edge Contrast Index (ECON) (Hoechstetter 2009) has been used for characterizing patch contrast (Formula 1). ECON equals the sum of the patch perimeter segment lengths p_k multiplied by their corresponding contrast weights (d_k), divided by the total patch perimeter (p), then converted into a percentage value (multiplied by 100). The dissimilarity value d_k assigns values between 0 and 1, with a value of 0 being assigned to the minimum difference in mean height between two adjacent patches. Conversely, a value of 1 is assigned to the maximum difference in mean height between two adjacent patches, edge segments along the landscape boundary are assigned $d_k = 0$. An in-between dissimilarity value is assigned according to the proportion of height difference to the maximum difference. In this paper, the minimum and maximum height differences are set in 0 m and 20 m.

Formula 1: $$ECON = \frac{\sum_{k=1}^{m}(p_k \times d_k)}{P} \times 100,$$

p_k : edge length of segment k;
d_k : contrast weight of segment k;
P : total patch perimeter;
m: number of patch segments.
Range: $0 < ECON \leq 1$

Landscape contrast

At a higher organizational level, it could be misleading to simply calculate the mean edge contrast for a particular patch type (class level) or for all patches (landscape level). An irregular-shaped small patch may play a disproportionately role in the overall land-

scape contrast. Therefore, a metric which refers to the patch proportions has been developed at the landscape level: Area-Weighted Edge Contrast (AWEC) (Formula 2). It is not only an accumulation of the edges' contrast value; meanwhile the area proportion of each patch is also incorporated. Based on the modified ECON, AWEC can be understood as average dissimilarity in vertical structure of habitats. The lowest value of AWEC is 0 when the whole landscape is considered as one patch (landscape boundary is assigned with dissimilarity of 0), and the highest value is 1 as all patches have hard edges (maximum dissimilarity).

Formula 2:
$$AWEC = \frac{\sum_{i=1}^{n} (a_i \times ECON_i)}{A}$$

n: number of patches in the landscape;
a_i: area of patch i;
$ECON_i$: the edge contrast value of patch k, see Formula 1.
A: area of the total landscape.
Range: 0 ≤ AWEC ≤ 1

Results

Comparison of contrast analysis with and without consideration of ecotones and small habitats

The contrast indices are calculated firstly in a vegetated area (test site 1) from a section of Saxon Switzerland (using the nDSM with horizontal resolution of 1 m and the land cover data). The results of landscape contrast analysis are shown in Figure 3. Having a look at the first case (a), the indices are calculated based on the land cover classes including forest and field without consideration of small habitats and ecotones. In the second case (b), the land covers are at a more detailed level of the land surface including small habitats and ecotones. In the outcome of the calculation of Edge Contrast Index (ECON), Patch A in case (a) is considered as a whole forest patch adjacent to the field and has an edge contrast value of 81.25 %. In case (b), it is an assembly of two small forest patches connected by an ecotone. Compared to Patch A, Patch A_1 shows a lower ECON of 78. 07 % and Patch A_2 has also a lower ECON of 58.28%. The reason is the existing ecotones around Patch A that act as buffer area between forest and field, resulting in a lower average height contrast of Patch A_1 and Patch A_2 from their surrounding patches. Patch B is also divided into two separate parts in case (b). The Patch B_1 has a lower value of ECON compared to Patch B, while patch B_2 shows a higher ECON value of 83.46%. Patch B in case (a) is a representation of the average ECON value of two patches with different vertical structures. It shows that the strictly categorical model neglect the inner heterogeneity of patches. The large forest Patch C shows also a decreased value of ECON from case (a) to case (b). This is due to the detection of ecotones which can lower the height contrast between forest and field. Small habitats

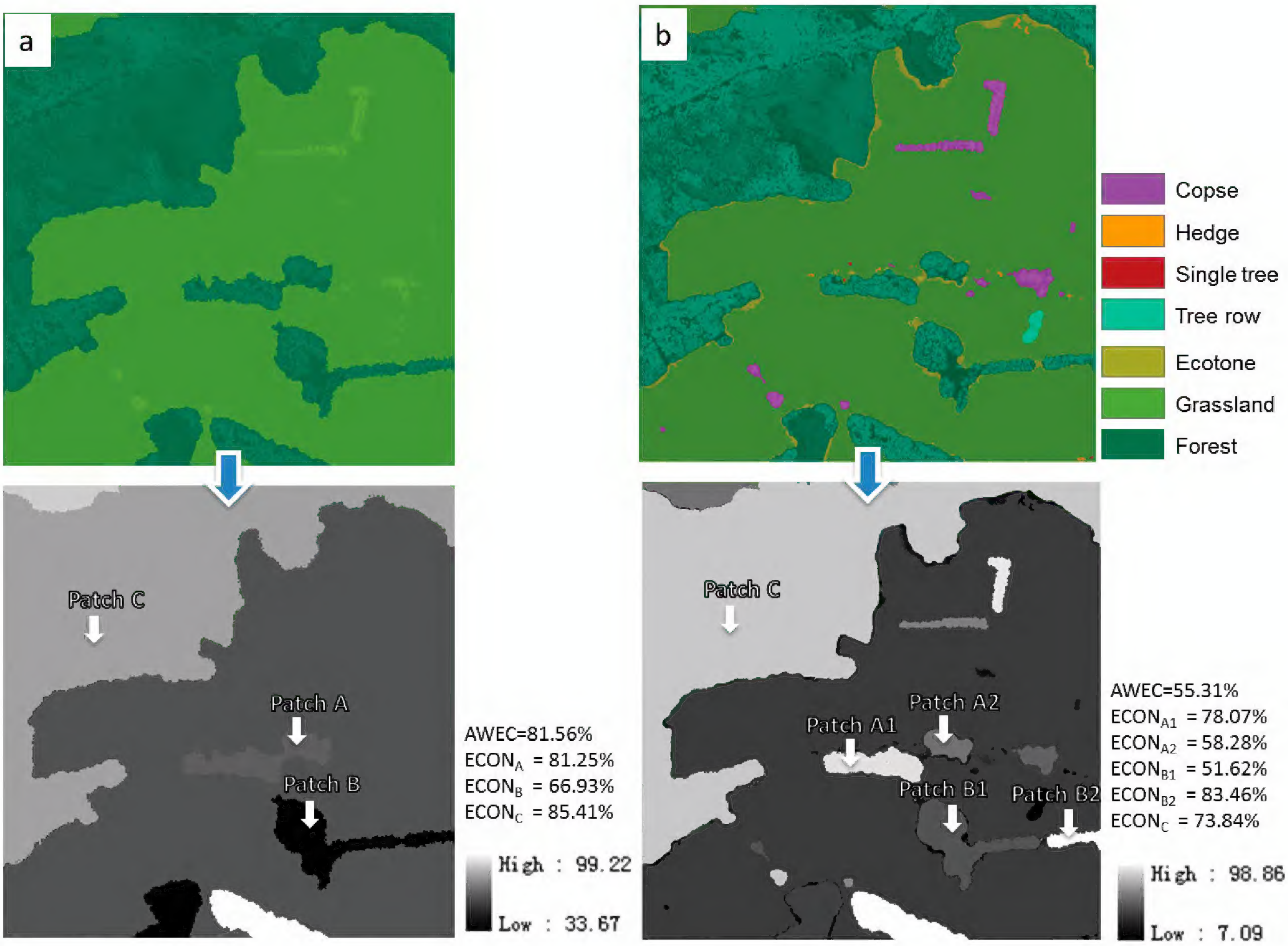

Figure 3. The applications of the adjusted Edge Contrast Index (ECON) and Area-Weighted Edge Contrast (AWEC) in the test site 1 (case (**a**) shows the results of contrast metrics without small habitats and ecotones; case (**b**) shows the results of contrast metrics including small habitats and ecotones).

mostly show lower contrast values than the large forest and field patches (Figure 3 (b)). They can partially alleviate the contrast value for the whole landscape, but the alleviation is limited due to their small area proportions. Although more patches are delineated in the case (b), the Area-Weighted Edge Contrast (AWEC) is still lower than in case (a). It means both ecotones and small biotopes possess low edge contrast values that can reduce the overall edge contrast of the whole landscape.

Comparison of contrast analysis with and without consideration of artificial elements

The patch contrast (ECON) is defined based on the vegetation height difference. But in reality there are often artificial elements existing in a vegetated landscape, e.g. traffic roads. We assume that the edges of artificial elements have the highest (100%) contrast weight to neighboring patches. A comparative test is exemplified in test site 2 (see Figure 4). The edge contrast values and landscape contrast are compared in two cases. Case (c) eliminates the traffic road and it is assumed as a vegetated area without artificial elements. Case (d), in contrast, shows a mixed landscape including both natural and artificial elements. Applying ECON and AWEC in both cases, the results

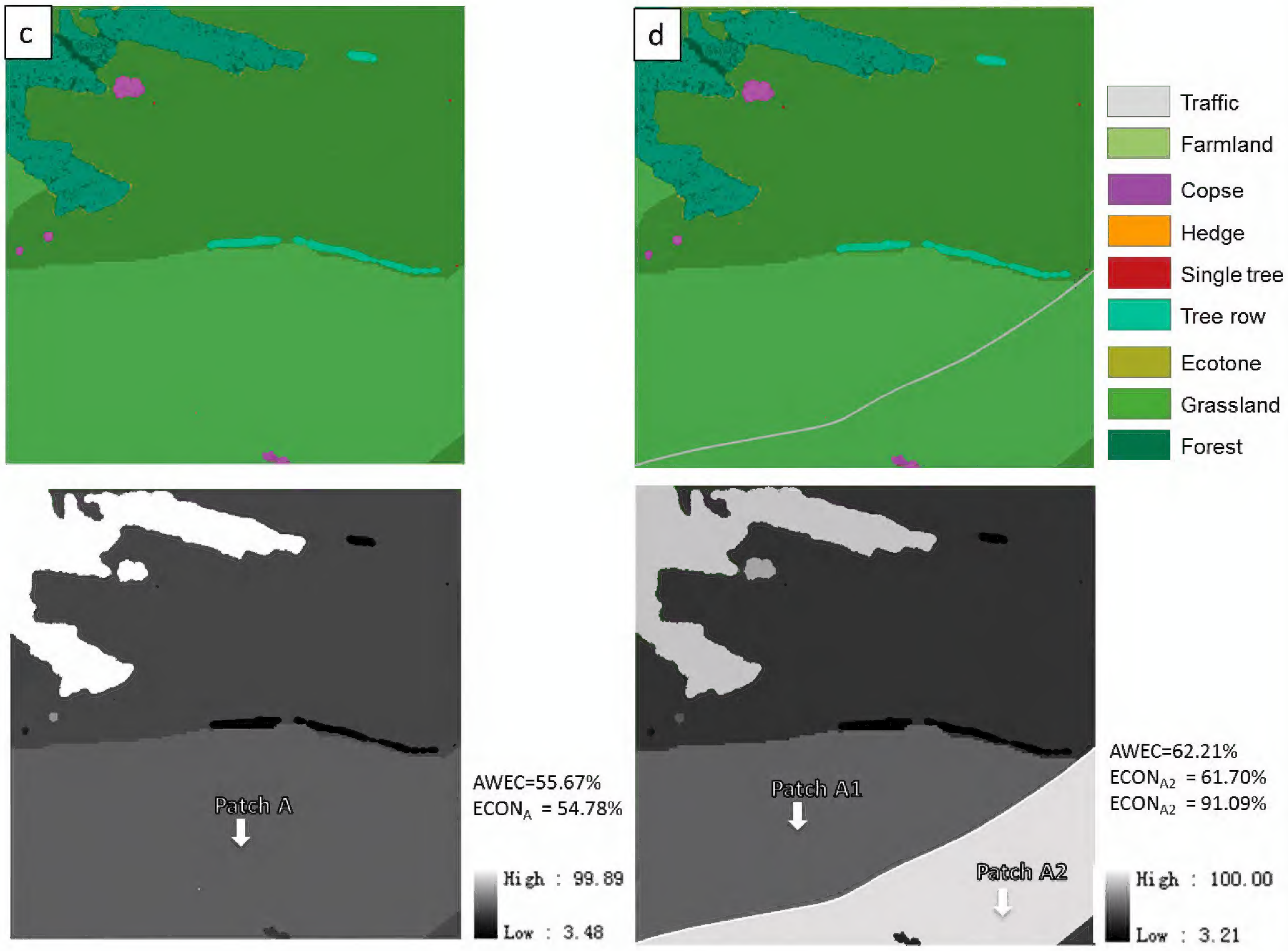

Figure 4. The applications of the adjusted Edge Contrast Index (ECON) and Area-Weighted Edge Contrast (AWEC) in the test site 2 (case (**c**) shows the results of contrast metrics without consideration of traffic road; case (**d**) shows the results of contrast metrics including traffic road).

are shown in Figure 4. In case (d), Patch A is dissected by a traffic road which increases the ECON of both Patch A_1 and A_2. This results in a higher AWEC on landscape level. The increased value of AWEC from case (c) to case (d) shows the effect of traffic road on landscape contrast.

Discussion

The use of models for quantifying landscape patterns

Patchiness and gradients are the concentrated expressions of spatial heterogeneity in the landscape (Wu 2007). Correspondingly two types of model have been used to represent landscape structure: Gradient Model (GM) and Patch Corridor Matrix Model (PCMM). Lausch et al. (2015) have concluded that the characteristics of research area and research objective are the decisive factors for choosing the appropriate model representing the landscape pattern. Landscapes under low human pressure are recommended for using the GM approach; anthropogenic-dominated landscapes should preferably be represent-

ed with the PCMM model. Furthermore, the research objective requires specific landscape metrics to be derived from relevant landscape model. In a natural landscape, the borders among heterogeneous vegetation are ambiguous. Thus, the surface metrics based on gradient model (e.g. Normalized difference vegetation index (NDVI), Topographic wetness (TWI), Greenness, etc.) are useful to capture the high transitory heterogeneity (McGarigal et al. 2009). In a cultural landscape, the land surface has been intensively used and managed by human, rendering the landscape in homogenous patches with distinct borders. The resulting landscape structure is therefore best represented with the PCMM approach, delineating patches of land-cover or land-use types by sharp borders.

In reality there is nearly no place without human impacts (Walz and Stein 2014). Official land use data (e.g. ATKIS (Amtliches Topographisch-Kartographisches InformationsSystem), the official German nation-wide digital database for topographic spatial data) often ignore the small habitats and ecotones. It seems that the remote sensing technology remains an experimental tool used in focal areas requiring standardized scientific methodologies for detailed habitat monitoring at the regional and national levels (Corbane et al. 2015). This could be the reason why the PCMM approach has been more frequently used in landscape structure analysis far beyond the GM. Since PCMM is originated from the human perception of landscape, it is straightforward, understandable and easy to use. Quantitative metrics can be easily established and a variety of software (Baker and Cai 1992, McGarigal et al. 2012, Rempel et al. 2012) based on PCMM has emerged and facilitated the knowledge transfer from theoretical model to practice. However, applying PCMM in a semi-natural landscape could be oversimplified by losing ecotones between patches. A possible solution for such problem could be incorporating the gradient concept into mosaic model to distinguish inner core patch and its transitional boundary. In this paper we apply the gradient concept in the mosaic model to represent the ecotones between forest and field, i.e. the interior of forest is regarded as the core patch, and the height gradient of vegetation between forest and field is considered as an ecotone. This applied landscape model represents the spatial heterogeneity in a more realistic condition. Human boundaries (i.e. traffic roads) can be integrated in landscape contrast analysis as barriers with highest contrast value. But this may arise further complexities (see below for the comparison between (Figure 3b) and (Figure 4d)). It makes more sense to differentiate the edge effect and barrier effect by using the concept of landscape contrast and fragmentation. As shown in Figure 5, the concept of landscape contrast unifies discrete and continuous landscape representations (GM and PCMM) (Biswas and Wagner 2012) and would be better applied in a vegetated landscape with intermediate edge contrast. In contrast, the concept of fragmentation is applied in a binary model, which highlights the edge contrast between patches, assuming both ECON and AWEC equal to 1.

The use of contrast metrics in different landscapes

At the patch level, the modified edge contrast index (ECON) measures the degree of height contrast between a patch and its immediate neighborhood. ECON is a relative

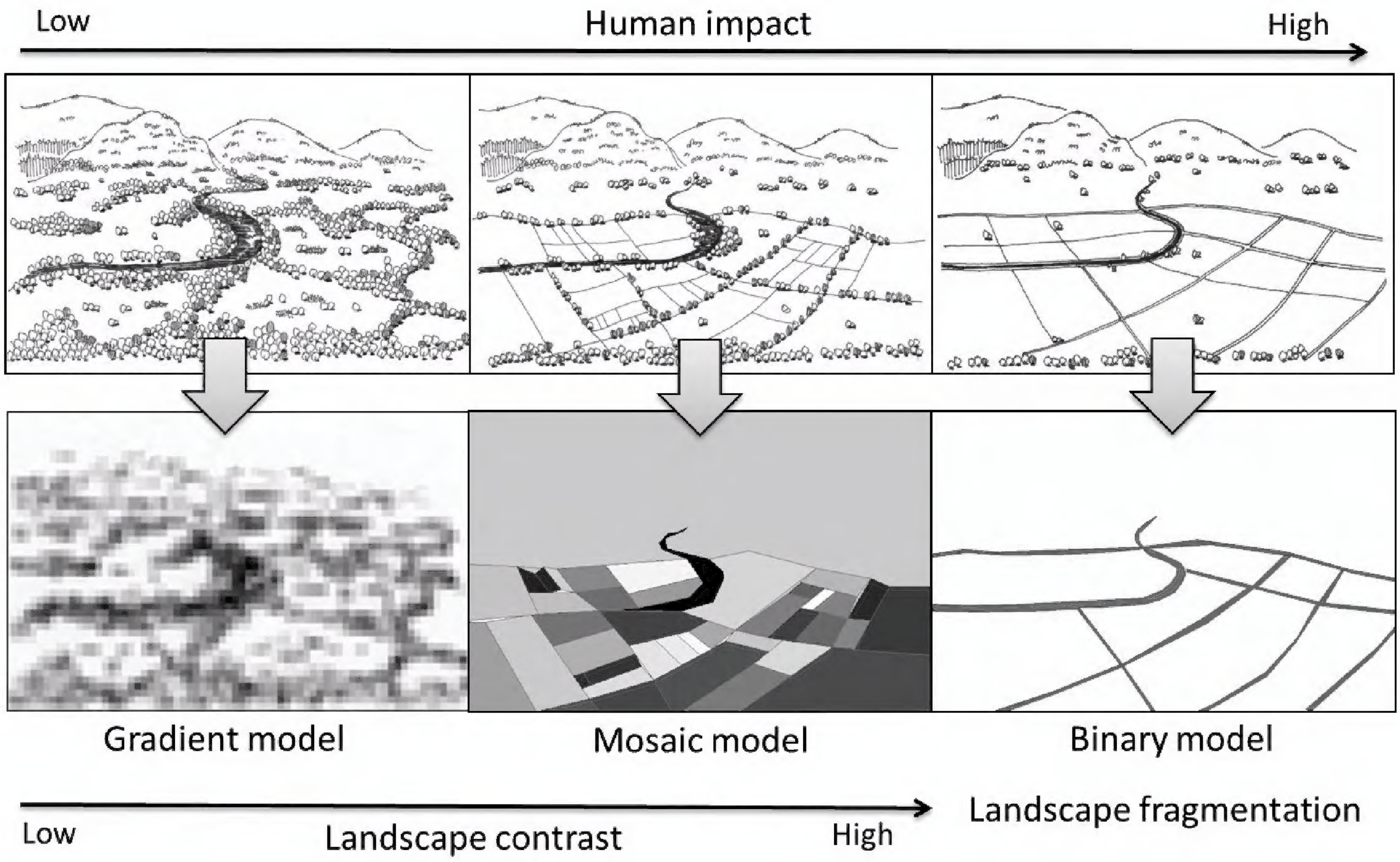

Figure 5. The conceptual models and metrics applied in different landscapes.

measure at patch level and stands for the degree of contrast in patch edge regardless of how big the patch is. At the landscape level, the edge effect have been often measured by Total Edge Contrast Index (TECI) or Contrast-Weighted Edge Density (CWED) (McGarigal et al. 2012), which count for all patches' edges multiplied by the corresponding contrast weight, divided by the total length of edge or total area in the landscape. The both indices only concern on the length of edges, regardless of the patch proportion. It would be helpful to quantify the edge contrast from the perspective of landscape configuration by using the Area-Weighted Edge Contrast (AWEC). This area-weighted index may be more appropriate than the unweighted mean index, since larger patches play a dominant role in the landscape dynamics. This index can also be applied in landscapes differing in total size and with differing proportions of habitat patches.

The examples shown in test site 1 demonstrate that the existence of small habitats and ecotones can reduce the landscape contrast as they possess the characteristic of lower edge contrast than the patch interior. In addition, the ecotones function as buffer areas or "soft boundaries" which reduce the height contrast between forest and field. The small habitats which are normally neglected in landscape structure analysis also account for the average height of matrix. For this reason, it is necessary to incorporate these small habitats and differentiate the patch interior and its exterior, such as ecotones. Attempts that incorporation of ecotones in fragmentation metrics (e.g. effective mesh size (MESH) (Jaeger 2000)) have been made to show the alleviation effects of landscape fragmentation by ecotones (Hou and Walz 2013). However, using the fragmentation metrics, the ecological functions of small habitats may be regarded as the perforation phase of fragmentation process according to their geometric characteristics

(Forman 1995, Jaeger 2000). This is contradicted to the perception that losing small habitats leads to landscape fragmentation (Jongman 2004). From the third dimension, the concept of landscape contrast can bring the ecological function of ecotones and small biotopes together. If the height difference among patches is considered as "terrain barrier", the ecotones or small habitats can be recognized as shift areas that influence transboundary movements.

Artificial elements (e.g. traffic roads) affect not only regional or metapopulation dynamics but also have a direct effect on local population dynamics (Pontoppidan and Nachman 2013). The examples shown in test site 2 present the effect of the traffic road in the analysis of landscape contrast. The results show that the traffic road has direct impact on its neighboring patches and leads to an increase of ECON values. As a result, the AWEC of the whole landscape has increased. In an anthropogenic-dominated landscape, the value of AWEC should be approaching to its maximum value 1. Comparing case (b) in test site 1 (Figure 3) and case (d) in test site 2 (Figure 4), test site 2 shows a higher landscape contrast value. But only using contrast metrics, it is hard to see the structure variation between the two test sites. It would be necessary to use the fragmentation metrics as an additional indicator to describe the dissected landscape by a traffic road in test site 2. A binary model can be used for this purpose, for example, all artificial elements will be assigned 1, other patches should be merged and assigned 0. Both landscape contrast and fragmentation metrics are needed to compare the habitat pattern of two test sites.

Conclusions

In this paper we present an integrated approach to analyze the landscape contrast as a means to describe landscape heterogeneity. Incorporation of gradient concept in landscape structure analysis helps to overcome the limitation of PCMM that valuable information on patch boundary is missing. Not like the gradient model, the integrated approach is still based on a classified map which contains an additional category of gradient elements, such as ecotones on forest/field boundary. Therefore, the robust metrics derived from PCMM can be adapted to quantify the landscape structure including gradients. Similar to PCMM, this approach has also limitations as the simplification of land surface may be affected by the classification schemes of land cover.

The modified contrast metrics in this study show different sensitivities to different landscape compositions. Comparison of applying contrast metrics in a vegetated landscape (Figure 3) has revealed that the introduced measures can full account for the effects of ecotones and small habitats and lead to improvements for characterizing the vegetation heterogeneity form the third dimensional perspective. Artificial elements with highest contrast weight can also be incorporated in the modified contrast metrics. They can significantly increase the contrast value of the landscape (Figure 4). Generally the introduced contrast metrics are more applicable for characterizing the landscape pattern with an intermediate human impact (Figure 5). As the human impact

increases, the landscape pattern would be better represented by the categorical model with strict borders and the fragmentation metrics are likely to be applied in this case.

Ecotones and small habitats are often ignored in landscape structure analysis. This may due to the fact that there is lack of suitable conceptual model and metrics to integrate them. Our experimental results have shown that the discussed approach (contrast metrics based on an integrated model) is efficient for implementation under different landscape composition. We suggest that greater attention should be paid to these detailed landscape elements at the local level.

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